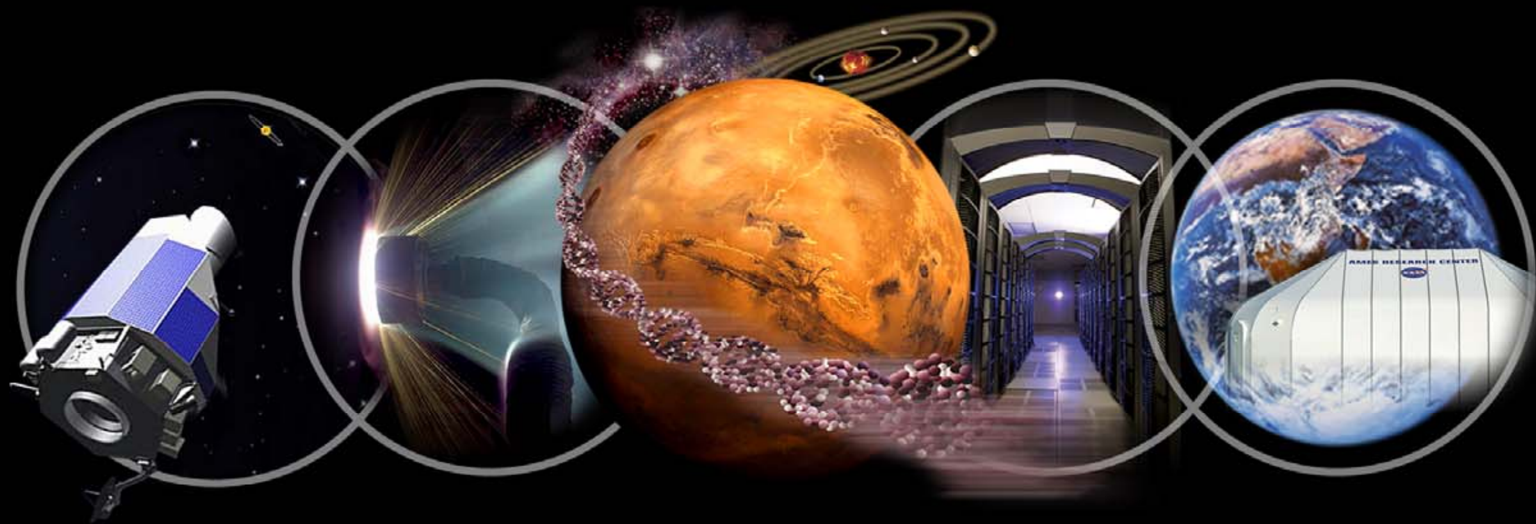
Discovery ➲ Innovation ➲ Solutions



# Mission Operations and Crew Assistance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NASA Ames Research Center

Visibility ➲ Excellence ➲ Impact

Ames Research Center

# Agenda

- Intro to mission operations and crew assistance
- Exploration drivers
- Ames capabilities overview
- Human-centered systems
- Situation awareness and decision support systems
- Multi-modal interfaces and human factors
- Complex information and knowledge management
- Conclusions

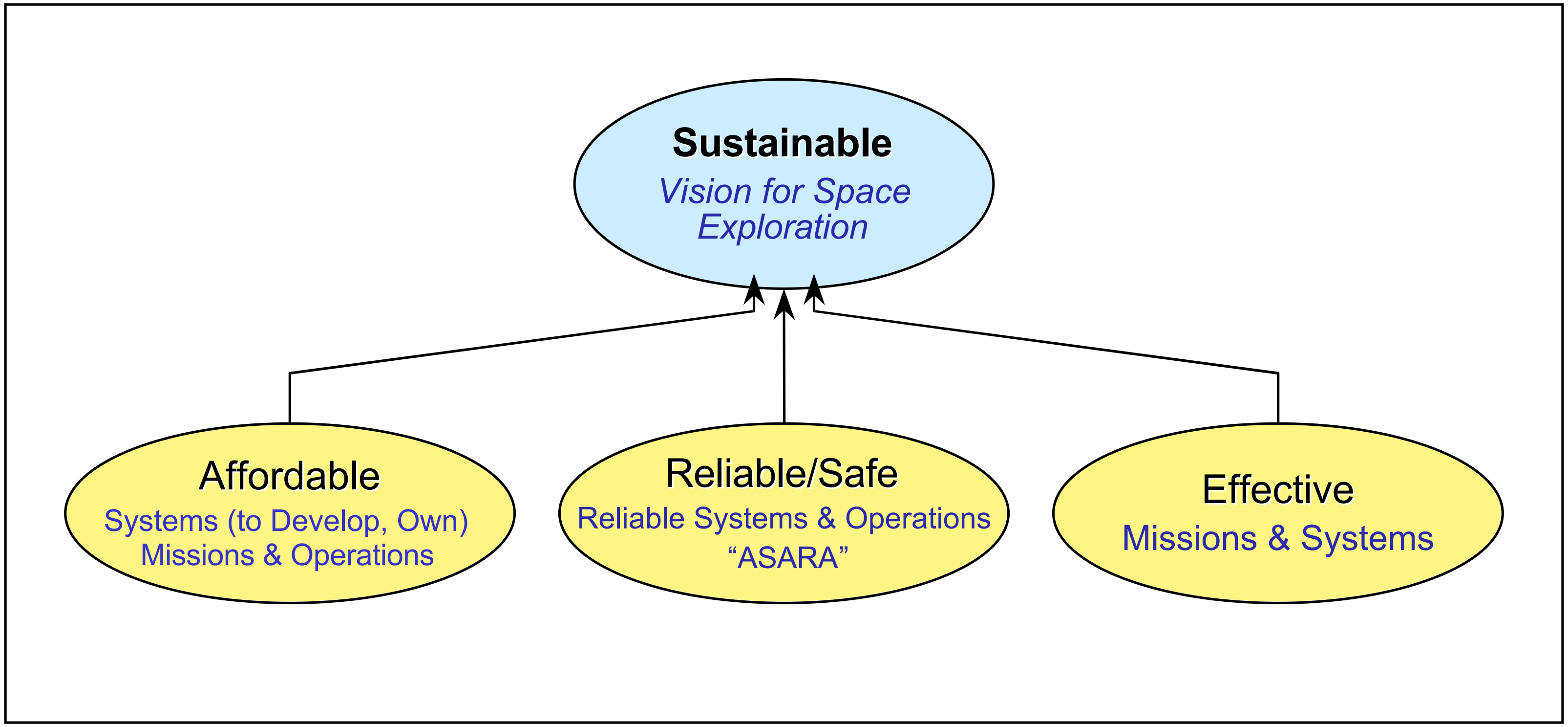
# Intro to Mission Operations and Crew Assistance

- **Mission viability, cost and safety is affected by the people responsible for its operation.**
- **People include:**
  - mission planners, launch and flight controllers
  - pilots and remote explorers
  - facilities and maintenance staff
  - myriad engineers responsible for preserving and applying knowledge
- **Activities include:**
  - procedure design, verification, training, execution, and support
  - communications, collaboration
  - knowledge and information management
  - operations, science, and exploration planning and scheduling
  - launch and range management
  - sustaining engineering, problem resolution, and what-if analyses
  - extra-vehicular activity planning, execution, coordination, and monitoring
  - human and robot interaction across time and space
- **Information technology has a dramatic influence on mission operations.**

# Driving Exploration Requirements

- **Spiral development methodology**
  - Systems must be designed to allow for evolution of capabilities.
  - Information technology capabilities will change radically over the duration of the exploration vision.
- **Reliable and affordable ground operations**
  - Reduced sustaining engineering costs
- **Self-sufficient and effective crew operations**
  - Crew time must be restricted to tasks that require the unique skills and abilities that human's provide.
- **In-flight training capability**
- **Extra-vehicular activities**
  - In-space assembly
  - Long-duration lunar and planetary operations
- **Human and robotic synergy**
  - Robotic capabilities must be designed for effective operations by people
  - Co-located and remote operations approaches

# A Sustainable Exploration Vision




*A sustainable Vision depends on…*

# "System-of-Systems" Challenges: Mapping

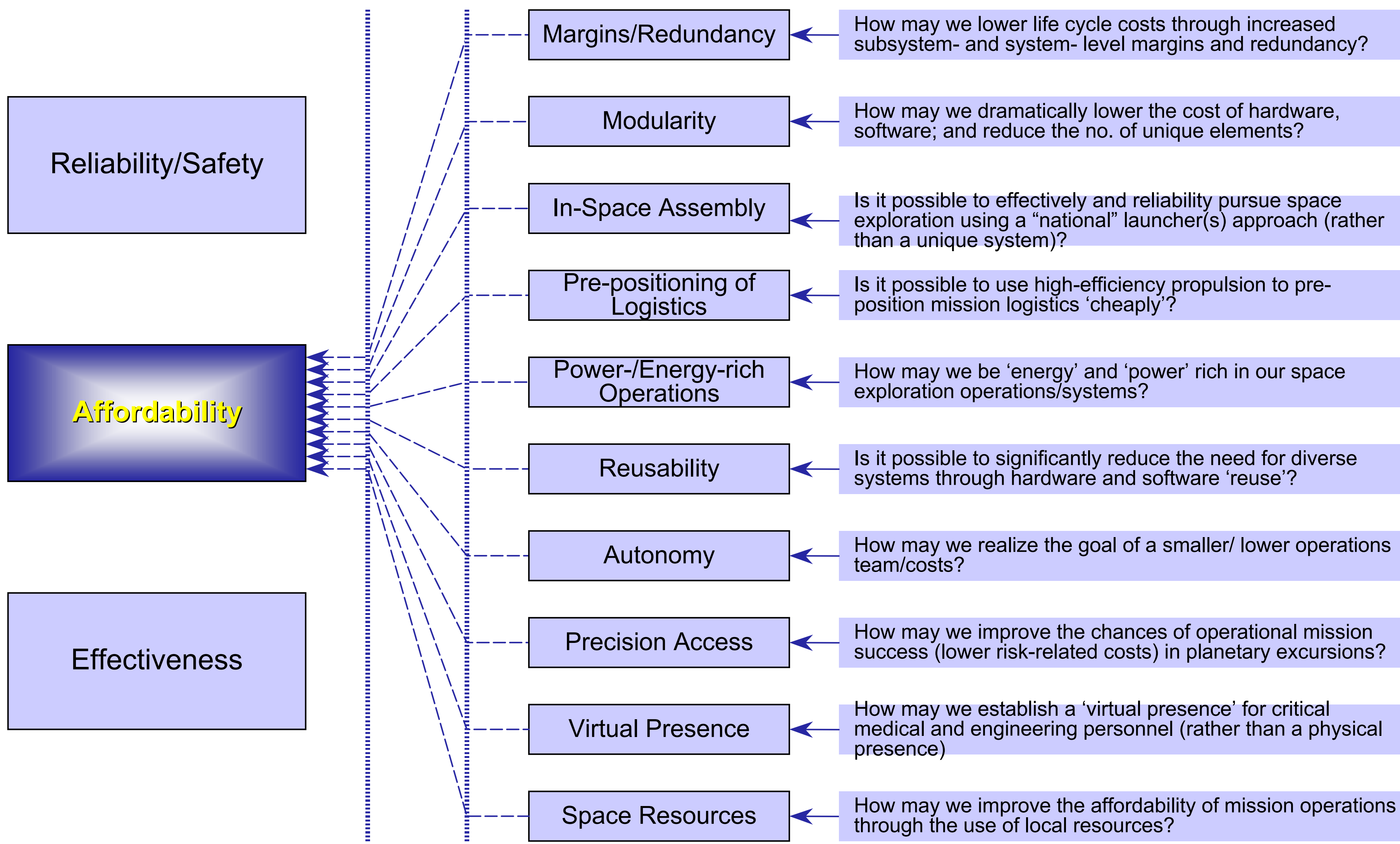
**Reliability/Safety**

Affordability

Effectiveness

| | |
|---|---|
| Margins/Redundancy | How may we improve reliability and safety at all levels through increased redundancy and common, readily integrated spares? |
| Modularity | How may we improve reliability and safety at all levels through the application of modularity and common, readily integrated spares? |
| In-Space Assembly | How may we increase reliability and safety through 'flexibility' by enabling the capability to reconfigure and repair systems? |
| Pre-positioning of Logistics | How may we increase reliability and safety through 'flexibility' by enabling the capability to pre-position systems, consumables and spares? |
| Power-/Energy-rich Operations | How may we increase reliability by assuring the power and energy are abundant (rather than scarce) for all key applications? |
| Reusability | How may we minimize the risks associated with 'first use' of systems, and the burden of extensive testing of new subsystems and systems? |
| Autonomy | How may we increase reliability and safety through more locally self-reliant systems and operations? |
| Precision Access | How may we improve safety and reliability of planetary operations in hazardous venues when logistics/systems may be delivered over time? |
| Virtual Presence | How may we increase safety through tele-medicine, and reliability through remote, high-quality engineering? |
| Space Resources | How may future missions be made safer and more reliable at the mission level through the availability of space resources? |

# "System-of-Systems" Challenges: Mapping



# "System-of-Systems" Challenges: Mapping

- Reliability/Safety
- Affordability
- **Effectiveness**

| | |
|---|---|
| Margins/Redundancy | How may increased margins and redundancy (at various levels) allow future operations that are more robust and flexible--and which accomplish more than otherwise? |
| Modularity | How may we increase effectiveness by making it easier to reconfigure systems an software to adapt to changing needs? |
| In-Space Assembly | How may we deploy and operate future 'systems-of-systems' that are larger than those possible with a single launch? |
| Pre-positioning of Logistics | How may we increase mission effectiveness through local refueling and re-supply using pre-positioned systems and vehicles? |
| Power-/Energy-rich Operations | How may we enable more ambitious mission operations and objectives through increased local power/energy in diverse venues? |
| Reusability | How may we most cost-effectively employ each deployed system across multiple mission phases and missions? |
| Autonomy | How may we increase effectiveness by local 'decision-making' by people and machines to minimize round-trip-light-time (RTLT) delays? |
| Precision Access | How may we realize more effective surface missions across multiple landings at diverse sites? |
| Virtual Presence | How may we increase the effectiveness of mission operations by enabling remotely located scientists to be 'virtually present'? |
| Space Resources | How may we employ local resources to allow future exploration mission to accomplish much more than would otherwise be possible? |

# Human and Robotic Technology
# Strategic Technical Challenges (1)

**Margins and redundancy**

in diverse subsystems, systems and systems-of-systems—but particularly those that must execute mission critical operations (such as transportation or life support) with the prospect of significant improvements in robustness in operations, reliability and safety.

**Reusability**

using vehicles and systems during multiple phases of a single mission, and/or over multiple missions instead of 'throwing away' crew transportation, service modules, propulsion stages, and/or excursion systems after only a single mission.

**Modularity**

employing common, redundant components, subsystems and/or systems that can improve reliability and support multiple vehicles, applications and/or destinations—with the potential for significant reductions in cost per kilogram.

**Autonomy**

making vehicles and other systems more intelligent to enable less ground support and infrastructure, including the goal of accelerating application of 'COTS' and COTS-like computing and electronics in space.

**ASARA" Human Presence in Deep Space**

making it possible for humans to operate affordably and effectively in deep space and on lunar/planetary/other surfaces for sustainable periods of operations—while assuring that they are 'as safe as reasonably achievable'.

# Human and Robotic Technology
# Strategic Technical Challenges (2)

## In-Space Assembly

docking vehicles and systems together on orbit instead of launching pre-integrated exploration missions from Earth using very heavy launch vehicles, and including in space maintenance, servicing, reconfiguration, evolution, etc., for exceptionally long-duration deep space operations.

## Reconfigurability

deploying systems that can be reconfigured following initial deployment, to enable adaptation to new circumstances, evolution at the systems-of 'systems level as new elements are added, or to support high level system options.

## Robotic Networks

enabling 'networks' of cooperating robotic systems to be deployed that can work cooperatively to prepare landing sites, habitation, and/or resources and to extend the reach of human explorers.

## Affordable Logistics Pre-positioning

sending spares, equipment, propellants and/or other consumables ahead of planned exploration missions to enable more flexible and efficient mission architectures.

# Human and Robotic Technology
# Strategic Technical Challenges (3)

**Energy-Rich Systems and Missions**

including both cost-effective generation of substantial power, as well as the storage, management and transfer of energy and fuels to enable the wide range of other systems-of-systems level challenges identified here).

**Space Resource Utilization**

manufacturing propellants, other consumables and/or spare parts at the destination, rather that transporting all of these from Earth.

**Data-rich virtual presence**

locally & remotely, for both real-time & asynchronous virtual presence to enable effective science and robust operations (including tele-presence and tele-supervision; tele-science; etc.).

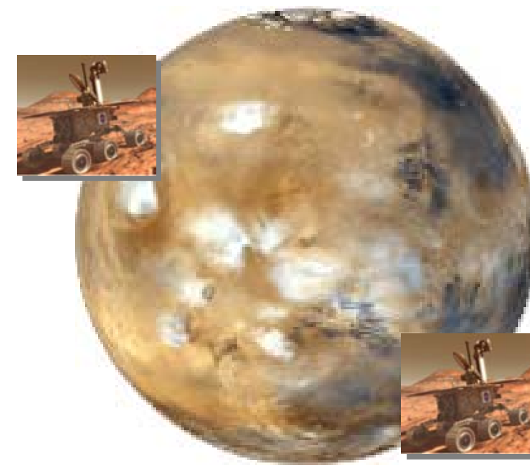
**Access to Surface Targets**

that is precise, reliable, repeatable and global for small bodies, the Moon, Mars and other destinations—including both access from orbit and access from other locations on a planetary surface through the use of advanced mobility systems.

# Ames Capabilities for Mission Operations and Crew Assistance

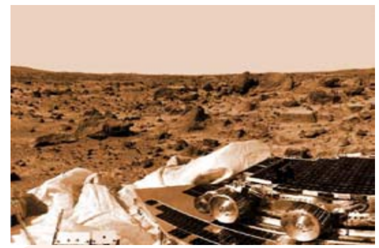
- **Human-centered systems**
  - design, evaluate, and enhance entire work-systems of people, facilities, devices, procedures, communications, information, and support technologies relative to mission objectives.
- **Situation awareness and decision support systems**
  - improve situation awareness and support decision making
  - in complex, mission-critical situations.
  - mixed-initiative planning and scheduling tools
  - launch and range management systems
  - Integrated simulations supporting what-if analysis
- **Multi-modal interfaces and human factors**
  - more natural and effective capabilities for people to interact with:
    - robots, information systems, and each other
    - across time and space
- **Complex information and knowledge management**
  - heterogeneous and evolving data, information, and knowledge
  - over all phases of a mission and across missions

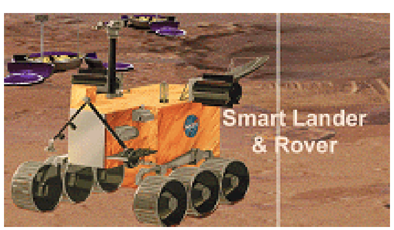
# Robotic Exploration of Mars



## Sojourner facts

- Max distance from Lander: 12 M
- Total distance traversed 100M
- Time spent waiting: 40-75%
- 2.4 uplinks per science target
- Science cut in half during extended mission






## MER – Facts

- It takes the MER rover a day to do what a field geologist can do in about 45 seconds. -- Steve Squyres MER 2003 PI
- Amortized cost of MER is $4 to 4.5 M per day of operation. (90 day mission)
- 240 co-located ground support scientists and engineers

## Mars Science Laboratory Challenges

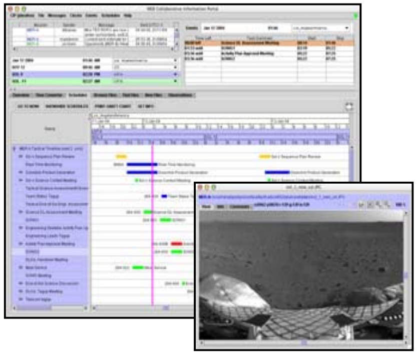
- Launch in 2009
- 600 day stay on the surface
- Single cycle instrument placement
- Large, distributed ground team

# Ames Capabilities for Mars Exploration Rover (MER) Mission Operations

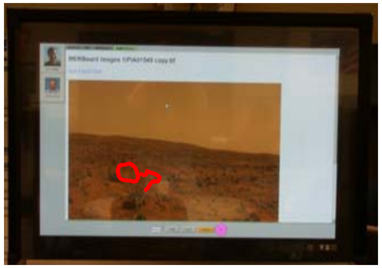
MER science and uplink team members have estimated that **overall science return increased by more than 20%.**

MAPGEN: Activity plan development and analysis

Viz: High fidelity terrain modeling and analysis



CIP: Customizable data navigation, search, and information management



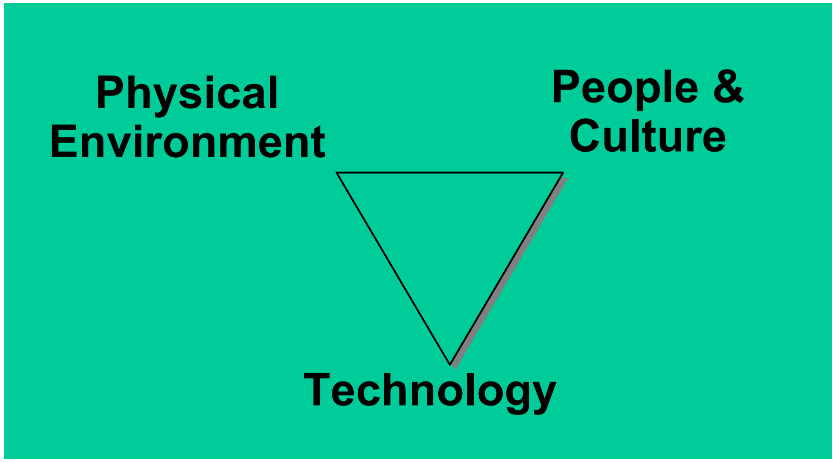
MERBoard: Collaborative information analysis and sharing

HCC & Fatigue Countermeasures: Improved data understanding and Enhanced situational awareness

# Human-centered systems

- **Work-systems design, modeling, simulation, and evaluation**
- **Procedure design, modeling, validation, training, and execution support**
- **User-centered design**
- **Integrated field tests**
- **Crew and team organizational design and modeling**
- **Flight deck and mission operations facilities design and evaluation**

# Human-Centered Systems




## Some technology pitfalls:

"Build it and they will come."

"… but it's a *great* technology."

"Lets just ask them what they want."

**Human-Centered Systems:** **A systematic methodology for designing systems that optimize the teaming of humans and machines.**

## Key Design principles:

***View design as cooperative action,***

***Be open to mutual learning between users and designers.***

***Observe the users work-practice***

***Help workers envision future work situations.***

***Start in the practice of the users  not the technology of the designers,***

**An *analog* is an activity performed in a representative environment that is similar to a feature of a mission.**

**Mission**

**Feature mapping**

**Analog**

## Objectives:

**Learn:**
- Understand requirements driving our exploration vision by doing real stuff.

**Test:**
- Test, validate and demonstrate technology, operations concepts and system interaction.

**Train:**
- Train crew, ground teams, managers and technologists in modes and challenges of exploration.

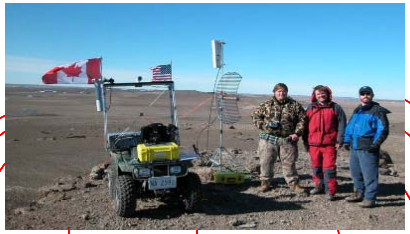
**Engage:**
- Engage the public in the exploration vision through analog missions.

# Human-Robot Analog Field Tests and R&D

Antarctic McMurdo

Marsokhod Kilauea

Haughton Mars Project



Mobility Study

1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005

Dante in Volcano

Nomad Atacama

K-9 and JPL's Fido

Utah Mars Station

Amboy Crater

Painted desert

K-9 Quarry

Arctic Deep Drill

# Applied Human-Computer Interaction

user & task research

user data collection

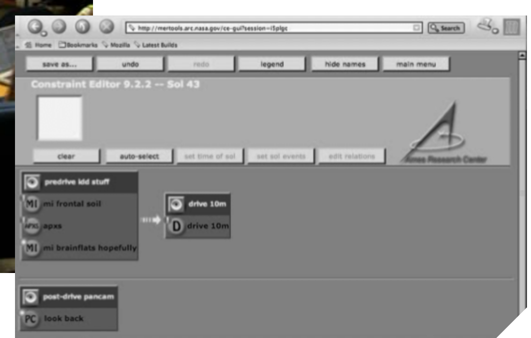
in situ data collection

design → implement → deploy → redesign

iterate

human performance modeling

Reliable design of tools enables crew, mission operations, and human-robotic team activity




Constraint Editor (MER): efficient, learnable, and less error prone mission tools

# Mobile Agents: Coordinating Human-Robot Interactions

Robot in "follow me" mode

Robot Mule tracks Astronauts & takes photos when commanded

Astros can work fully in parallel, talking to personal agents

## Utah Field Tests 2003 and 2004

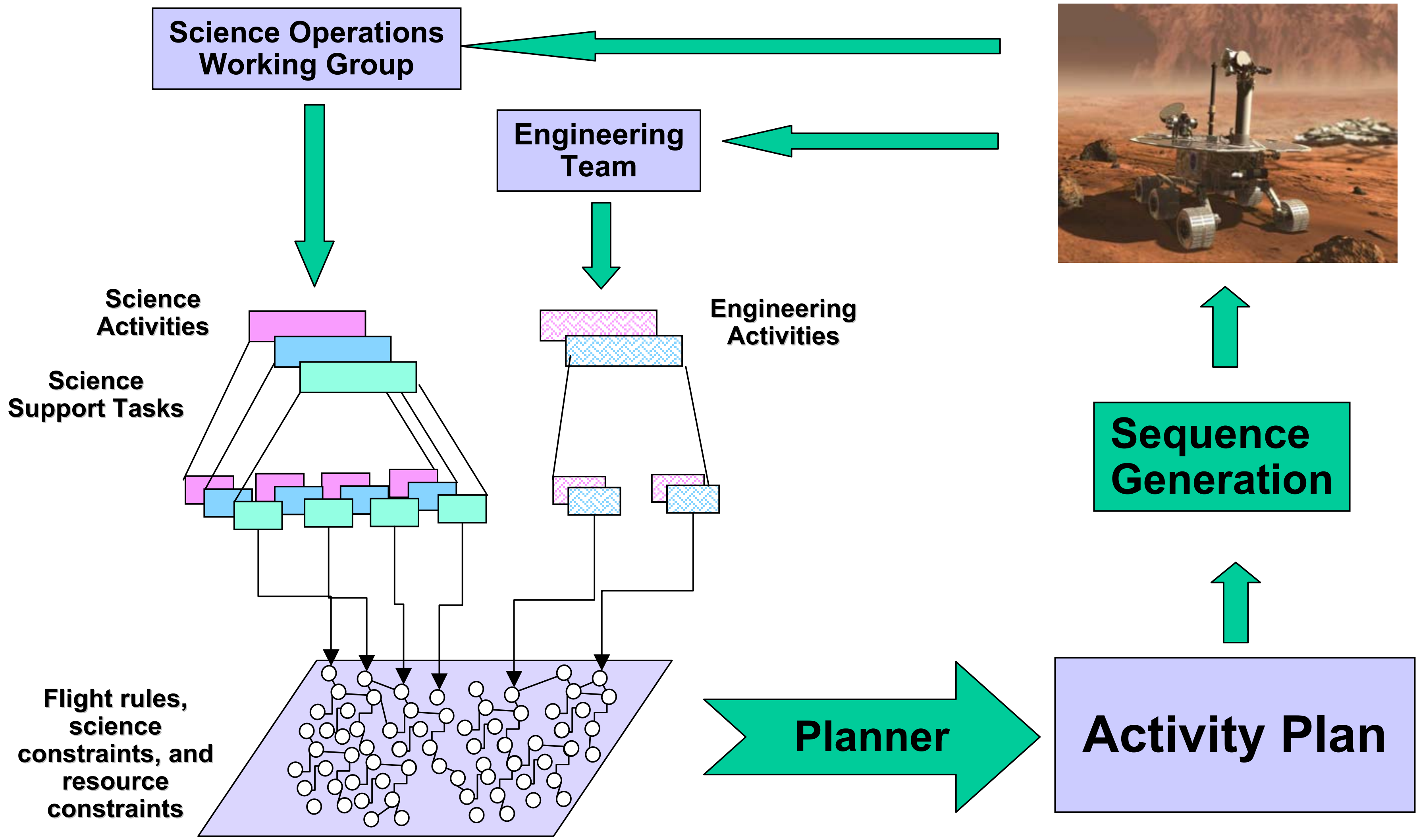
- 50 Participants over 17 days
- 3 NASA centers & 2 universities
- Diverse scenarios, rough terrain
- 2 geologists; authentic science

Voice annotation is recorded and transmitted to database in habitat & to RST on earth

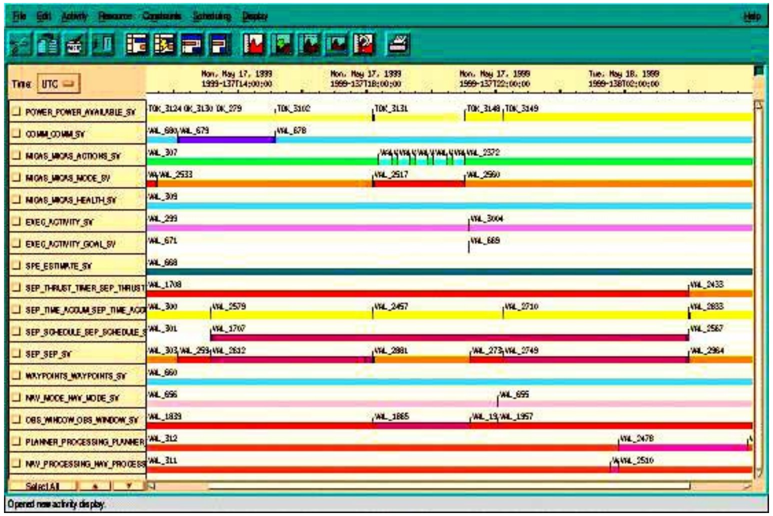
# Situation Awareness and Decision Support Systems

- **Mixed-initiative planning and scheduling, constraint checking, resource management**
- **Launch and range modeling and operations**
- **Virtual Iron Bird technologies**

# Mars Exploration Activity Planning



# Mixed Initiative Planning and Sequence Generation



Planning System

MER science and uplink team members have estimated that **overall science return increased by 20 to 50%.**

- Plan science observations, while **enforcing constraints**
- Detect & repair **resource violations**
- Safely tweak plan with **constrained activity moves**
- Perform rapid **what-if** analyses

# Intelligent Launch & Range Operations


# Virtual Iron Bird Technologies and SimStation: A Systems Thinking Workbench for Space Station

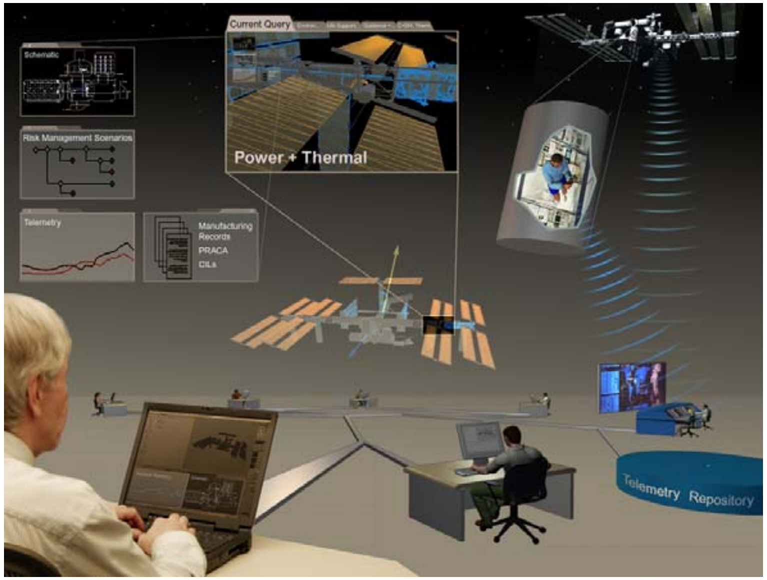
## Problem Statement

International Space Station (ISS) system interactions are growing more complex as construction proceeds.

Getting a coordinated view is very labor intensive

## Technical Approach

- Extend Engineering Document Repositories to be Systems Thinking tools
- Create a virtual vehicle that integrates models across many engineering disciplines; telemetry & document access
- A workspace for analyzing complex trades




## Impact

- ISS geometry & environment capability in regular use by ISS Vehicle System Engineers (VIPER)
- Quick-look behavioral model by end of FY04

# Multi-modal interfaces and human factors

- **Speech, dialog, gesture, audio tones**
- **Extension of human senses**
- **Visualization, virtual reality, heads-up displays, augmented cognition**
- **Usability and cognitive models**

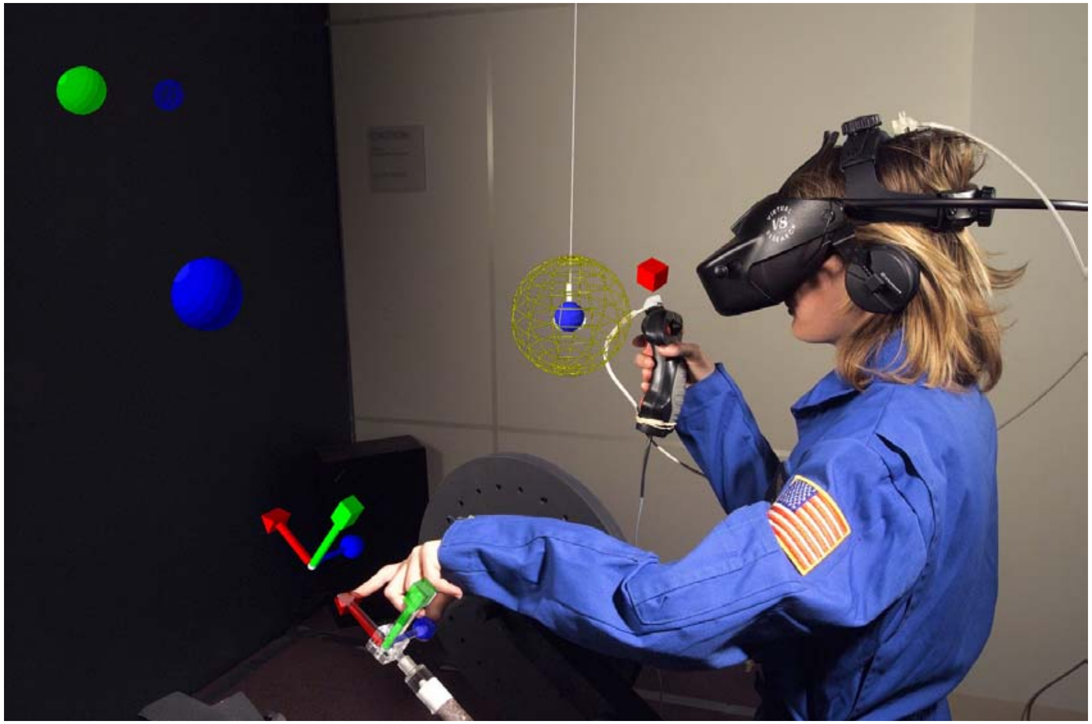
# Virtual Environment Technologies

## Multi-modal displays and Direct Interaction

- Visual and Haptic Interfaces & Spatial Cognition
- Spatial (3-D) Audio
- Predictive Head-Tracking

For

- Remote Operations
- Collaborative Engineering
- Telepresence
- Training



http://human-factors.arc.nasa.gov/ihh/spatial/research.html

# Virtual Environments for Training and Design

## System Lag

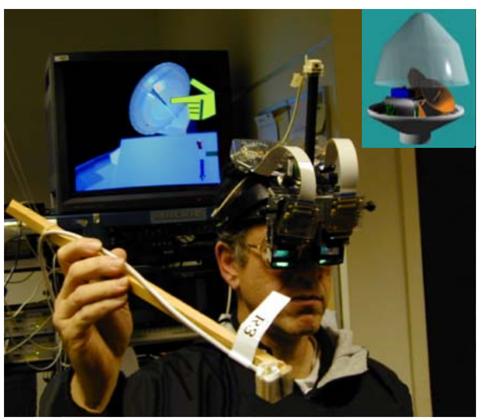
Perceptual artifacts of predictive filtering have been determined. Spacecraft virtual assembly testbed is implemented for predictor studies

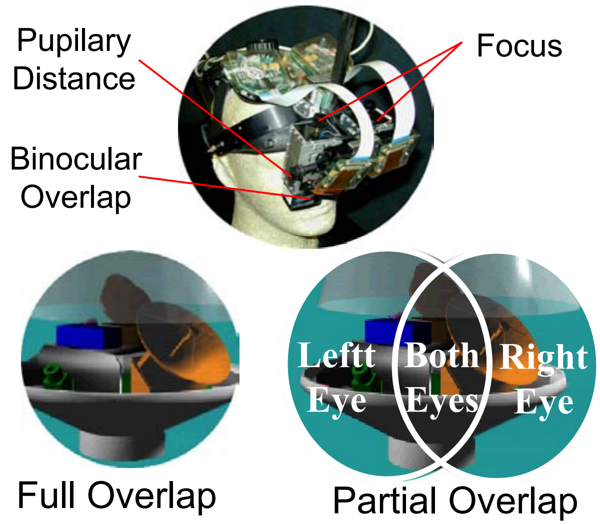
## Limited Field of View

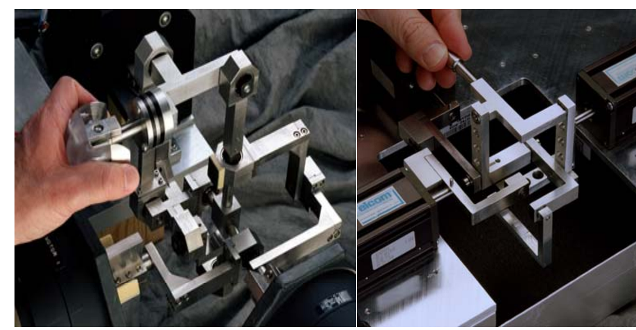
Reconfigurable, stereoscopic see-through HMD testbed has been developed to extend field of view by partial binocular overlap.

## Haptic Feedback

High fidelity arm- & finger- scale haptic interfaces completed with performance surpassing COTS technology.





Perceptually tuned predictors minimizing artifact detectability: Design and user validation studies have been conducted

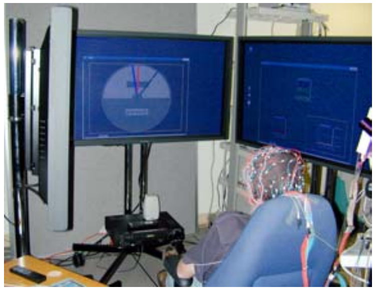
User visual fatigue, stereoscopic accuracy, and tolerance for optical distortion will be studied in part task simulation.

High fidelity haptic-visual virtual assembly testbed is being developed for human performance evaluation

# Extension of the Human Senses

## Overview:

- Advanced sensing devices used to detect EEG and EMG signals.
- Machine learning algorithms used to interpret and classify signals.
- Subtle signal variations detected and use for a diverse range of control demonstrations.



## Demonstrations:

- Floating keyboard.
- Air-piloting shuttle landing.
- Sub-vocalization for "thought control"

# Spoken Dialog Assistant Systems

## Problem:

- Astronauts perform numerous **tasks where they need to both obtain information about activities and use their hands.**
- Use of a **keyboard in zero-gravity** is cumbersome.

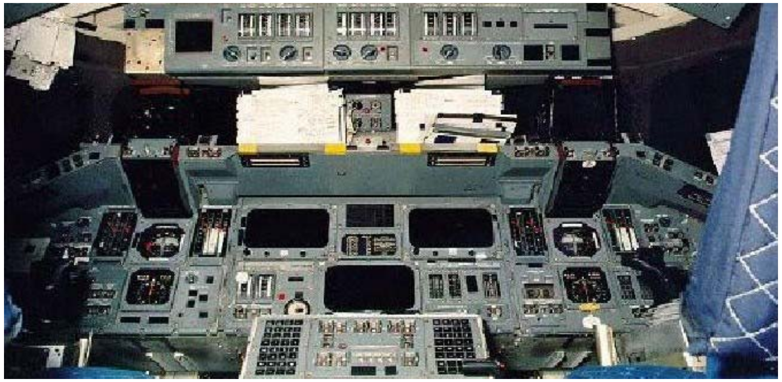
## Solution:

- **Ames has been developing spoken dialogue systems since 1999** to assist astronauts and allow them to interact with the computer using natural language.
- Systems are able to **track the dialogue to maintain context**

## CLARISSA Flight Experiment: Intelligent Procedures and Checklists

- Allows astronaut to **interact using natural language** with an intelligent procedure/checklist system.
- **Eliminates the need for an astronaut to read** the procedure while one does the procedure.
- Strong **support from the astronaut office**.
- Path-finding flight experiment **opening the door to a wide range of intelligent astronaut assistant technology.**

# Shuttle Cockpit Upgrade Project



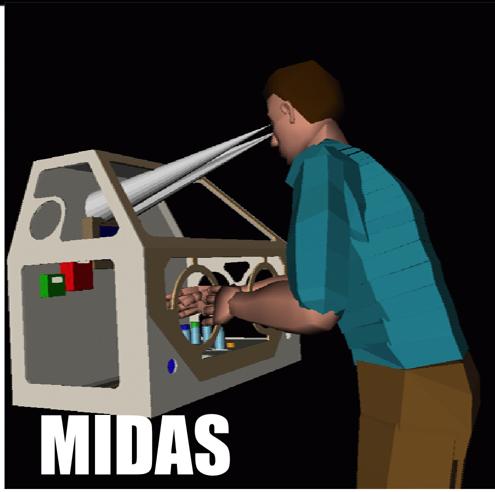
## Background

- Ames-JSC Joint Activity Initiated in 1999
- ARC personnel integrated into both planning and implementation phases

## Impact & Benefits

- SCU project obtained Ames' expertise in space human factors
- Ames personnel became familiar with real Shuttle vehicle and operational requirements
- Relationships developed for future collaborative projects

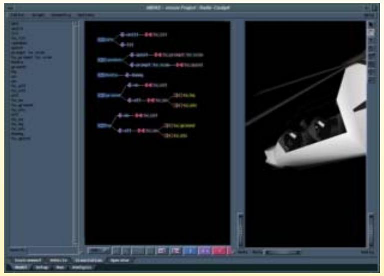
# MIDAS



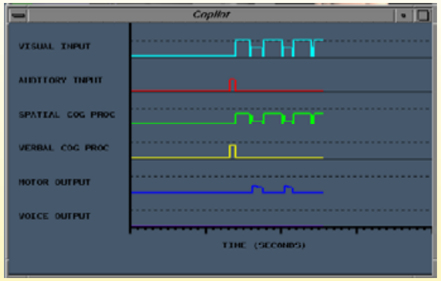

**The Man-Machine Integration Design and Analysis Simulation** (MIDAS) has been under development at Ames for nearly two decades with primary support from the US Army Aeroflightdynamics Directorate.

MIDAS offers an integrated human performance modeling environment to simulate, evaluate and visualize notional designs & procedures in a virtual operational environment.

**Goal:** Model life sciences glove box to predict challenges of use in micro-gravity, to develop more efficient science procedures and more effective training.

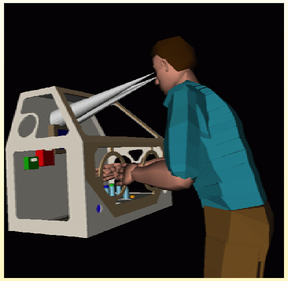


**Data Input**




**Data Analysis**

**Off-Line Human Factors Analysis**

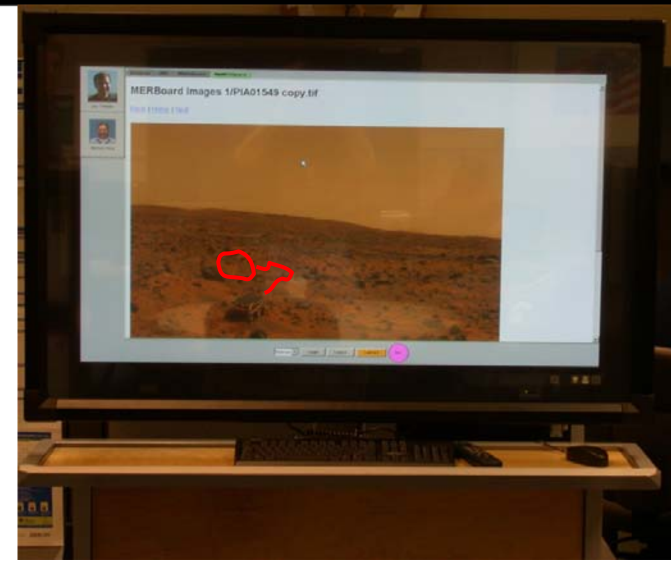


**Run Time Visualization**

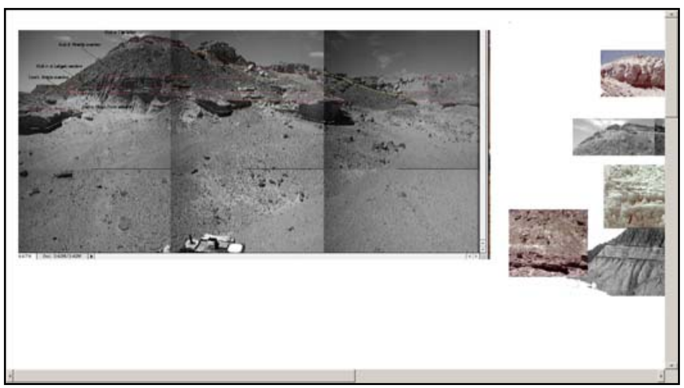
# Complex information, knowledge management, and collaboration technologies

- Structured, XML, and unstructured search and information retrieval
- Distributed databases and storage concepts
- Semantic data organization, metadata management, and ontologies
- Lessons learned and expertise capture
- Middleware and interoperability components, services and portals
- Distributed and asynchronous communication approaches

# Collaboration with Complex Information: MERBoard




**MERBoard is an electronic whiteboard with an enhanced and expanded interface developed by Ames researchers to facilitate information analysis, collaboration, sharing and distribution.**



**"MERBoard is a great success! ,..I am very impressed by what I see… two times I saw groups turned away because both (MER) boards were being used"**

**… S. Sqyres, MER Science PI.**

- **Strategic Planning Team** used MERBoard regularly to develop "Sol Trees" for planning purposes. Other groups wait to use a MERBoard because they are in such high demand.
- **Geology Theme Group** generated this MERBoard Stratigraphy Analysis and presented to the science team. (more on following slide)

# Conclusions

- **Exploration vision will require advanced capabilities in mission operations and crew assistance**
- **Ames has a pipeline of key capabilities to address the strategic technical challenges in the human and robotic technologies program**
- **Major areas of focus include:**
  - Human-centered systems
  - Situation awareness and decision support systems
  - Multi-modal interfaces and human factors
  - Complex information and knowledge management
- **Ames has a track record of delivering world class components and partnering for large-scale mission operations systems**

# Backup slides